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FUNDAMENTALS OF HUMAN BIOMECHANICS IN AN UNSUPPORTED SITUATION

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(Academy of Sciences of the USSR)

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ABSTRACT

The authors discuss the problem of orientation in space by man through his own efforts. Rotation of the body in weightlessness, the effect of moving one or both arms and the legs, and the most effective methods of rotating in a supportless situation are among the subjects treated. Rotation with the help of legs was found to be most effective. On the basis of the results presented the authors assert that after special training a man in a supportless situation will be able to orient himself quickly and accurately in any direction solely by his own muscular effort.

One important problem in space flight is the study of the qualitative /1* and quantitative aspects of movements made by a man as he maneuvers in space under conditions of weightlessness. The absence of the force of gravity will change greatly man's coordination and the nature of his movements interacting with the bodies and objects around him, will require him to modify the motor activity to which he is accustomed, and will require him to redistribute his muscular effort. Even greater changes will have to be made in his motor activity when he is in a supportless situation and has no interaction with external forces. From the point of view of mechanics, in this case, a man will be a closed system.

Studying the nature of movements made by a man in a supportless situation is of great interest in space flight and is one of the leading problems of biomechanics being studied at the present time.

Of particular interest is the problem of orientation in space by man through his own efforts. This article is devoted to this problem.

After the basic research done by V. L. Kirpichev (1907), the arguments

*Numbers given in the margin indicate the pagination in the original foreign text.

about the possibility of turning in a supportless situation ceased. V. L. Kirpichev showed convincingly that the rotation of a man or an animal in supportless space around the body's center of mass not only did not contradict the law of conservation of momentum (law of conservation of area), but quite possibly was in complete agreement with this law of mechanics. He /2 suggested that a man would be able to rotate around the longitudinal axis of his body by conical movements of one arm over his head.

Based on these principles another Soviet scientist, R. Pol' (1930), recommended another method of arm movements to enable a man to rotate around the body's longitudinal axis.

It is obvious that it is possible to use the movement of not only one arm but both of them and also other parts of the body, for example, the legs. In this case, it is possible to rotate not only with respect to the longitudinal axis of the body but also with respect to other axes, the transverse and the sagittal. V. L. Kirpichev and R. Pol' offered only a qualitative, theoretical answer to this problem.

In order to select the most effective methods of rotating in a supportless condition and to give suitable recommendations for their performance, it is necessary first of all to have a quantitative description of the interaction of separate parts (links) of the human body. Moreover, in planning the main and auxiliary movements it is necessary to bear in mind the anatomical-physiological chacteristics of man.

We have calculated the moments of inertia of a human body and its sepa rate parts (links) according to Shteyner's theorem, using the formula:

$$I_o = I_c + ma^2,$$

where I_o is the moment of inertia of the body (link) with respect to the 0 axis; I_c is the moment of inertia with respect to the axis passing through the center of gravity of the body (link); m is the mass of the body (link); and a is the distance from the center of gravity to the 0 axis.

In turn, the moment of inertia, with respect to the axis passing through the center of gravity of the body (link), was determined from data due to Brown and Fisher using the formula:

$$I_c = m \cdot 0.091^2,$$

where 1 is the length of the body (link). The theoretical calculations were checked in experiments with the participation of specially trained subjects. The experiments were conducted using a horizontal rotating platform (a Zhukovskiy stand) and a toss-up net which made it possible to create a condition of weightlessness for a period of 1.0—1.5 sec. As a final step the subjects were tested under conditions of weightlessness in an aircraft flying along a Kepler parabola. The movement of each man was recorded using cinecyclograms taken at a rate of 24 and 90 frames/sec.

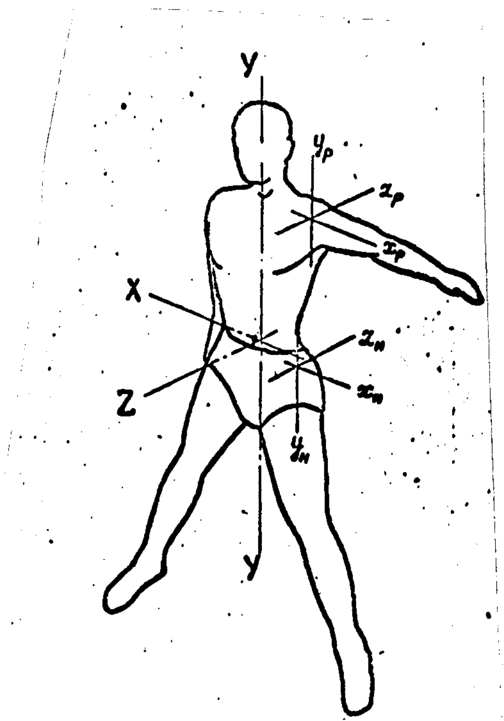
By theoretical calculations and experimental testing, the moments of inertia of the body and its separate parts (links) with respect to the various links for a man 168 - 172 cm tall and 70 - 75 kg in weight (see table and sketch) were determined.

TABLE /3

Moments of Inertia of a Body and Its Parts

Parts of Body	Moments of Inertia in kg-m^2 with Respect to Axes			
	Y	X	Z	Other
Body held erect	1,2 — 1,4	17,0 — 18,0	17,0 — 18,0	
Head, trunk and arms	0,55 — 0,65	3,8 — 4,4	3,8 — 4,4	
Arm held straight				X_p, Y_p, Z_p — 0,6
Leg held straight				X_n, Y_n, Z_n 1,9 — 2,2
Legs spread to sides or one in front of the other to form angle of:				
60 - 70°	2,6 — 3,3			
120 - 140°	3,9 — 4,4			
Erect body less arms				X_p — 24,0 — 28,8
Bent body less arms				X_p — 12,0 — 14,4
Body less one arm				Z_p — 27,6 — 30,0
Legs bent to form "angle"	3,8 — 4,4	3,8 — 4,4	0,50 — 0,55	

Establishing these values made it possible to compute moments of inertia of various parts of the body with respect to the different axes and then to evaluate, select, and give a justification for the most advisable methods of turning. Ease in performing the movements was taken into consideration. For example, in order to rotate about the longitudinal axis (in course) through 180°, using the method of V. L. Kirpichev and R. Pol', it is necessary to make 5 - 6 conical arm movements. In this event, the body will rotate not only about the "Y - Y" axis but also about the other axes. In our opinion, it is preferable to utilize the movement of both arms in a plane perpendicular to the axis of rotation. One such movement rotates the body through 60°. In preparing for a second cycle the arms are placed in the initial position, passing through a plane parallel to the axis of rotation. In this case, the side movement of the body is kept to a minimum.



Schematic drawing of man's body and axes of rotation. /4

Rotation with the help of the legs was found to be most effective. The initial position was with one foot placed far to the front of the other or with the legs spread to the sides. Depending on the position of the legs, it is possible in one cycle to rotate around the longitudinal axis through an angle of 160° or 90° since the moment of inertia of the legs with respect to the "Y—Y" axis is 7-8 times greater than the moment of inertia of the remainder of the body.

Rotations around the transverse (in pitch) or the sagittal (in bank) axes can best be executed using a circular movement of both arms in a sagittal plane (in the first case), or of one arm in a frontal plane with the body bent double. Naturally, increasing the moment of inertia of the arms by using objects tied to them (instruments and so on) increases the effectiveness of rotating.

The results which have been presented here give grounds to assert that after special training a man will be able, when in an unsupported situation to orient himself rapidly and precisely in any direction solely by his own muscular effort without resorting to his equipment.

Mastering various methods of orientation in a supportless situation should begin with the execution of different elements of the methods on a rotating horizontal platform (a Zhukovskiy stand). Learning a new motor stereotype, constantly making movement more complex, can be accomplished by performing exercises on rolling, toss-up, or other special stands. Great aid in learning to control one's body during free flight can be derived from acrobatics and especially by jumping from a tower into the water. Finally, as an essential step in the training, aircraft flights should be taken along a parabola of weightlessness, during which movement is practiced while carrying standard equipment. During these flights it is advisable to simulate various operations while using the necessary tools.

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